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Nagasaka

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(54) **MOTION ASSIST DEVICE AND MOTION ASSIST METHOD**

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A61H 3/06 (2006.01)
A61H 1/02 (2006.01)

(52) **U.S. Cl.**
CPC ***A61H 3/061*** (2013.01); ***A61H 1/0262*** (2013.01); ***A61H 3/00*** (2013.01); *A61H 2201/1215* (2013.01); *A61H 2201/14* (2013.01); *A61H 2201/1463* (2013.01); *A61H 2201/164* (2013.01); *A61H 2201/165* (2013.01); *A61H 2201/1628* (2013.01); *A61H 2201/5028* (2013.01); *A61H 2201/5061* (2013.01); *A61H 2201/5069* (2013.01)

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USPC 700/170, 245, 253, 254, 256, 260, 261; 601/33–35
See application file for complete search history.

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(57) **ABSTRACT**

There is provided a motion assist device including a jth link worn on a jth portion of a user, an ith joint unit connected at one end of an ith link in a freely rotatable manner, a (j+1)th link worn on a (j+1)th portion of the user, an (i+1)th joint unit integral with one end of the (j+1)th link and coupled to the other end of the jth link, a single actuator installed at one of the jth link and a link adjacent to the jth link, and a transmission part transmitting a driving force of the actuator to the ith joint unit and the (i+1)th joint unit.

12 Claims, 10 Drawing Sheets

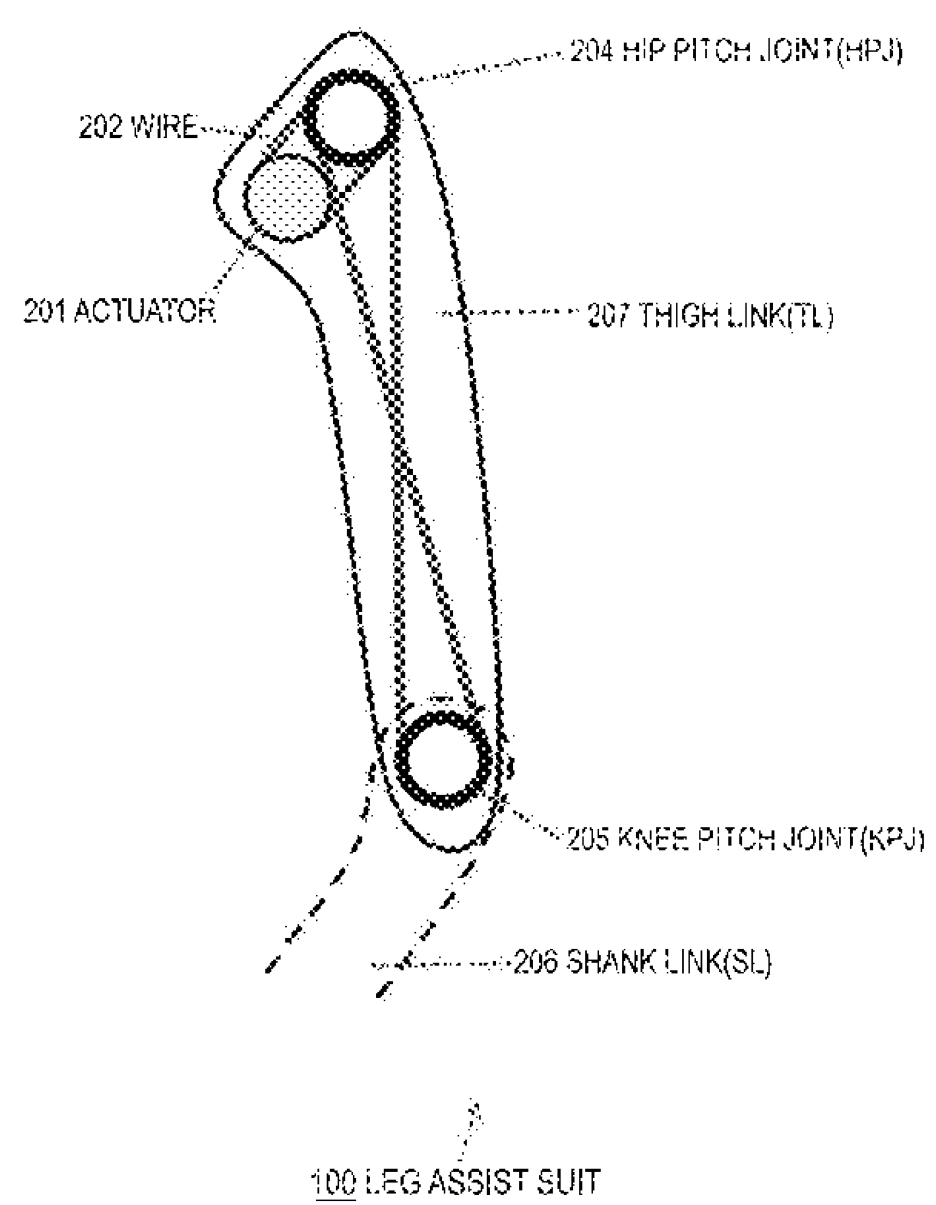

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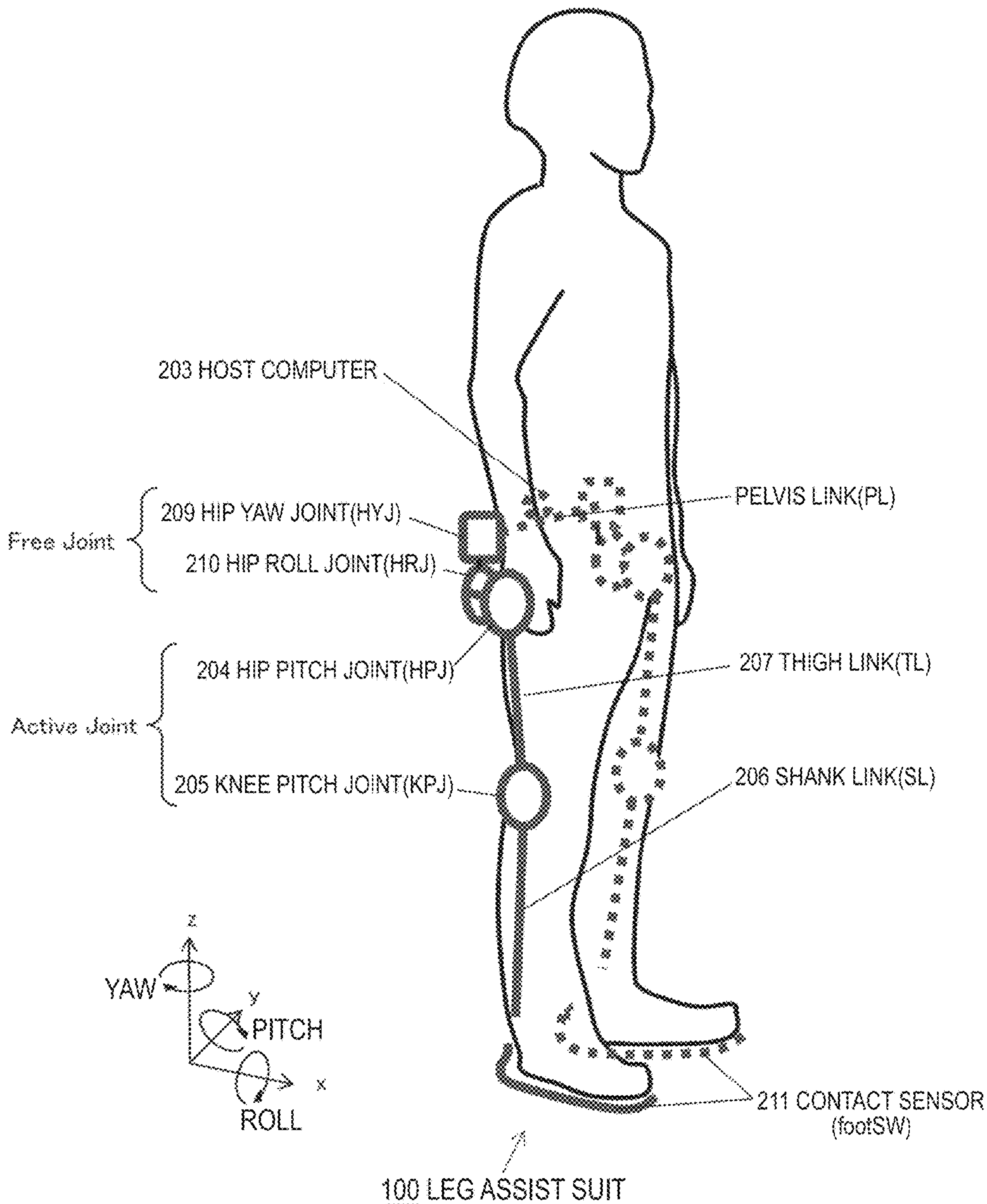
FIG. 1



203 HOST COMPUTER
209 HIP YAW JOINT(HYJ)
Free Joint
210 HIP ROLL JOINT(HRJ)
PELVIS LINK(PL)
204 HIP PITCH JOINT(HPJ)
Active Joint
205 KNEE PITCH JOINT(KPJ)
207 THIGH LINK(TL)
206 SHANK LINK(SL)
z
YAW
y
PITCH
x
ROLL
211 CONTACT SENSOR
(footSW)
100 LEG ASSIST SUIT

FIG. 2

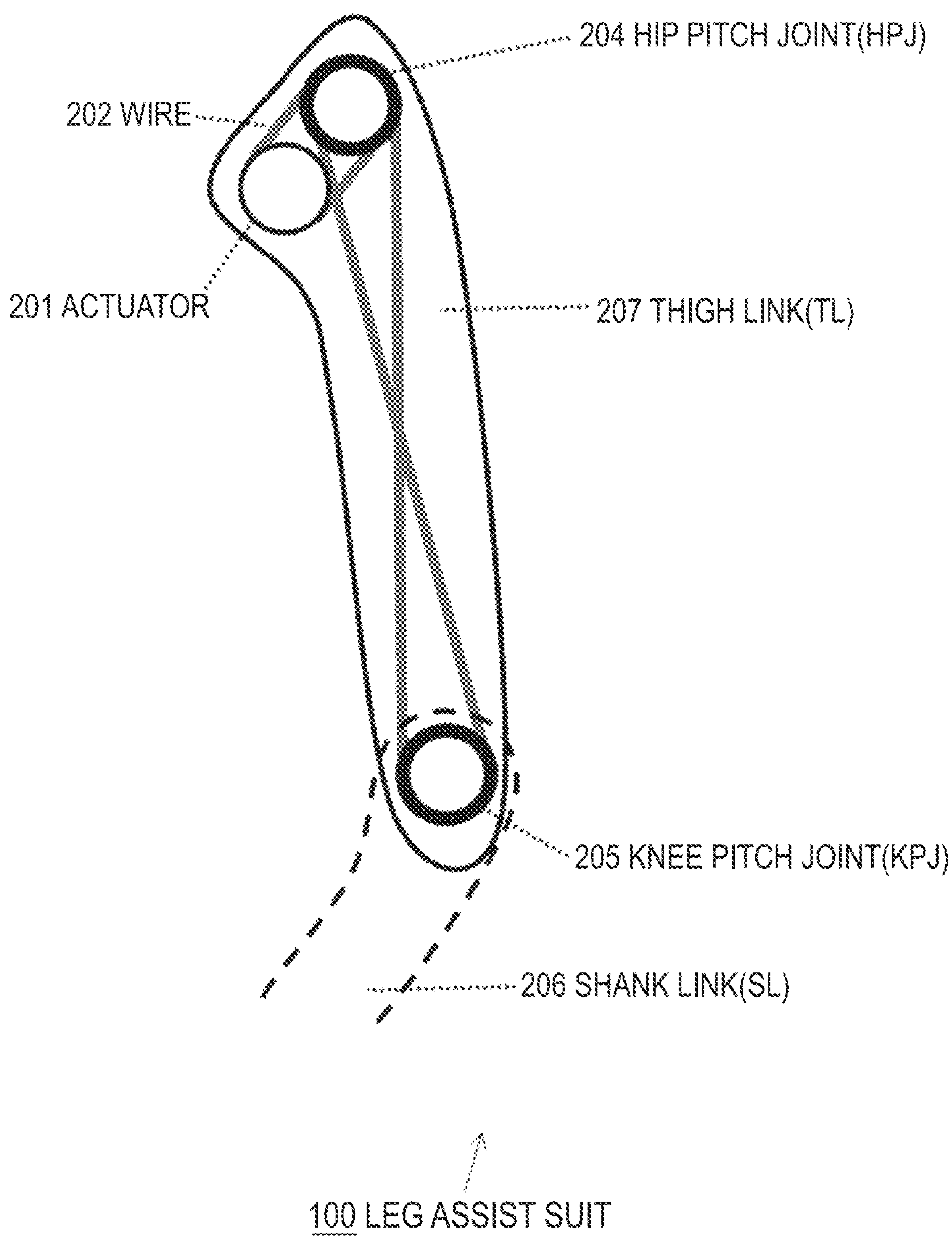
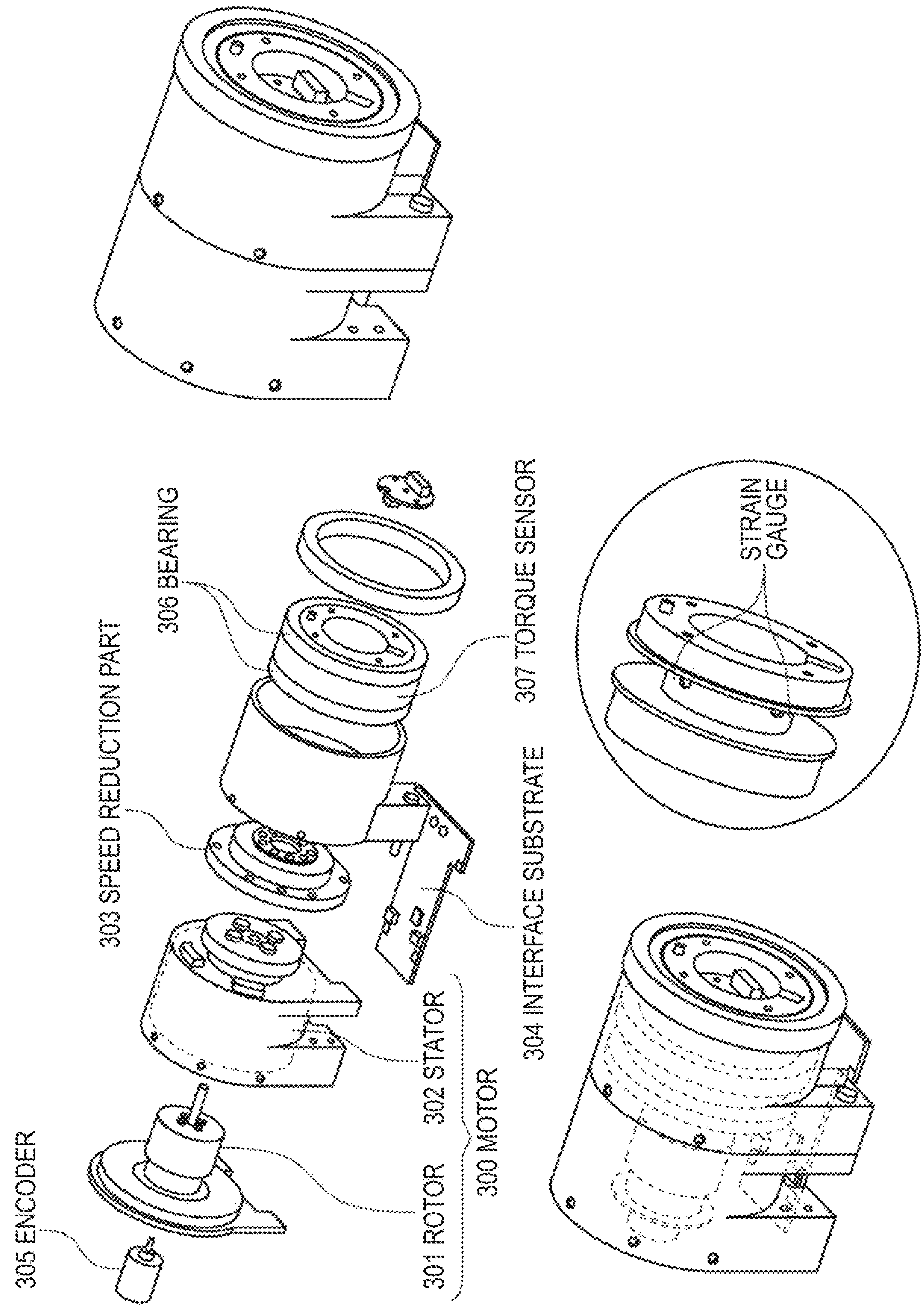

204 HIP PITCH JOINT(HPJ)
202 WIRE
201 ACTUATOR
207 THIGH LINK(TL)
205 KNEE PITCH JOINT(KPJ)
206 SHANK LINK(SL)
100 LEG ASSIST SUIT

FIG. 3



305 ENCODER
301 ROTOR
302 STATOR
300 MOTOR
303 SPEED REDUCTION PART
304 INTERFACE SUBSTRATE
306 BEARING
307 TORQUE SENSOR
STRAIN GAUGE

FIG. 4

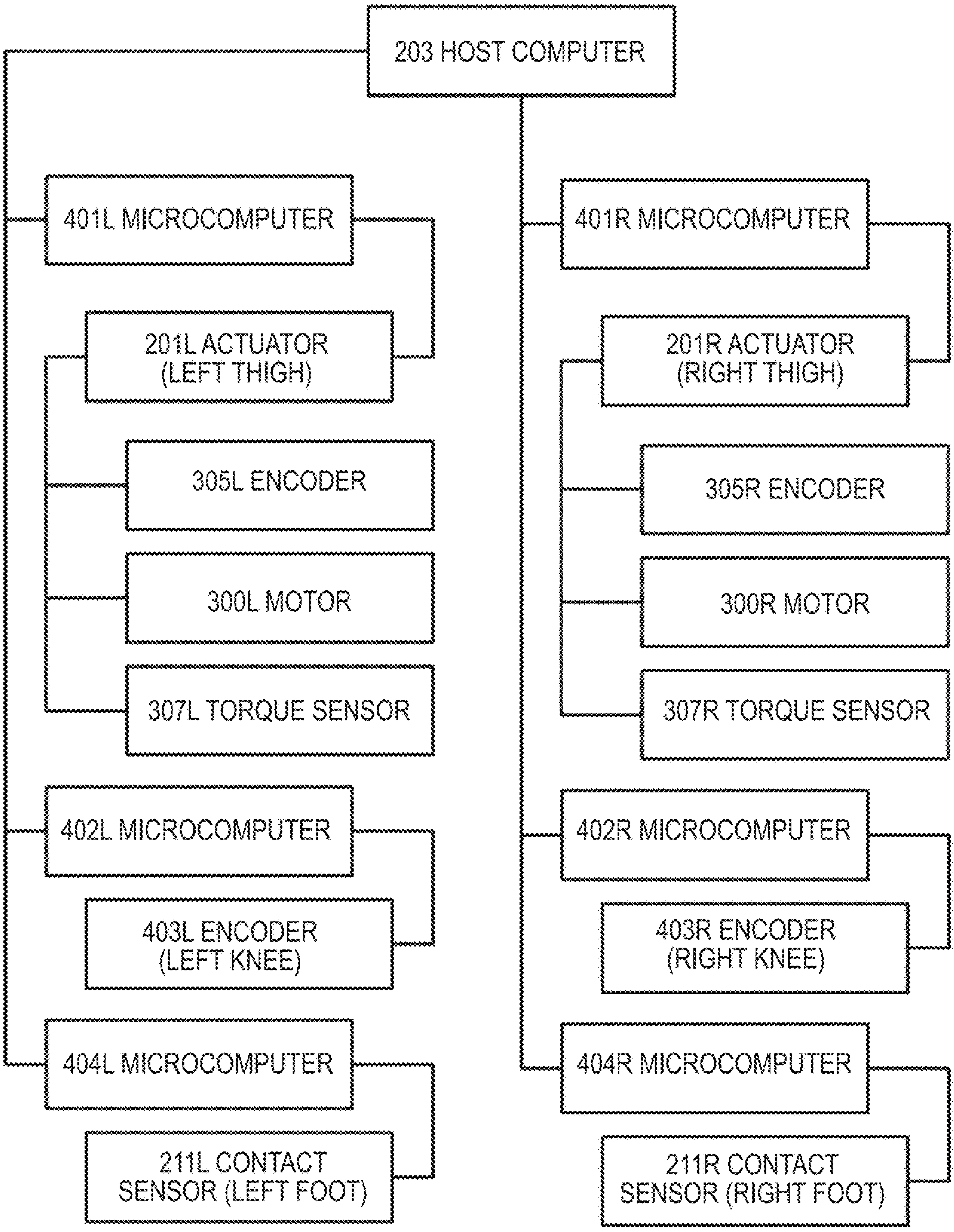

203 HOST COMPUTER
401L MICROCOMPUTER
201L ACTUATOR (LEFT THIGH)
305L ENCODER
300L MOTOR
307L TORQUE SENSOR
402L MICROCOMPUTER
403L ENCODER (LEFT KNEE)
404L MICROCOMPUTER
211L CONTACT SENSOR (LEFT FOOT)
401R MICROCOMPUTER
201R ACTUATOR (RIGHT THIGH)
305R ENCODER
300R MOTOR
307R TORQUE SENSOR
402R MICROCOMPUTER
403R ENCODER (RIGHT KNEE)
404R MICROCOMPUTER
211R CONTACT SENSOR (RIGHT FOOT)

FIG. 5

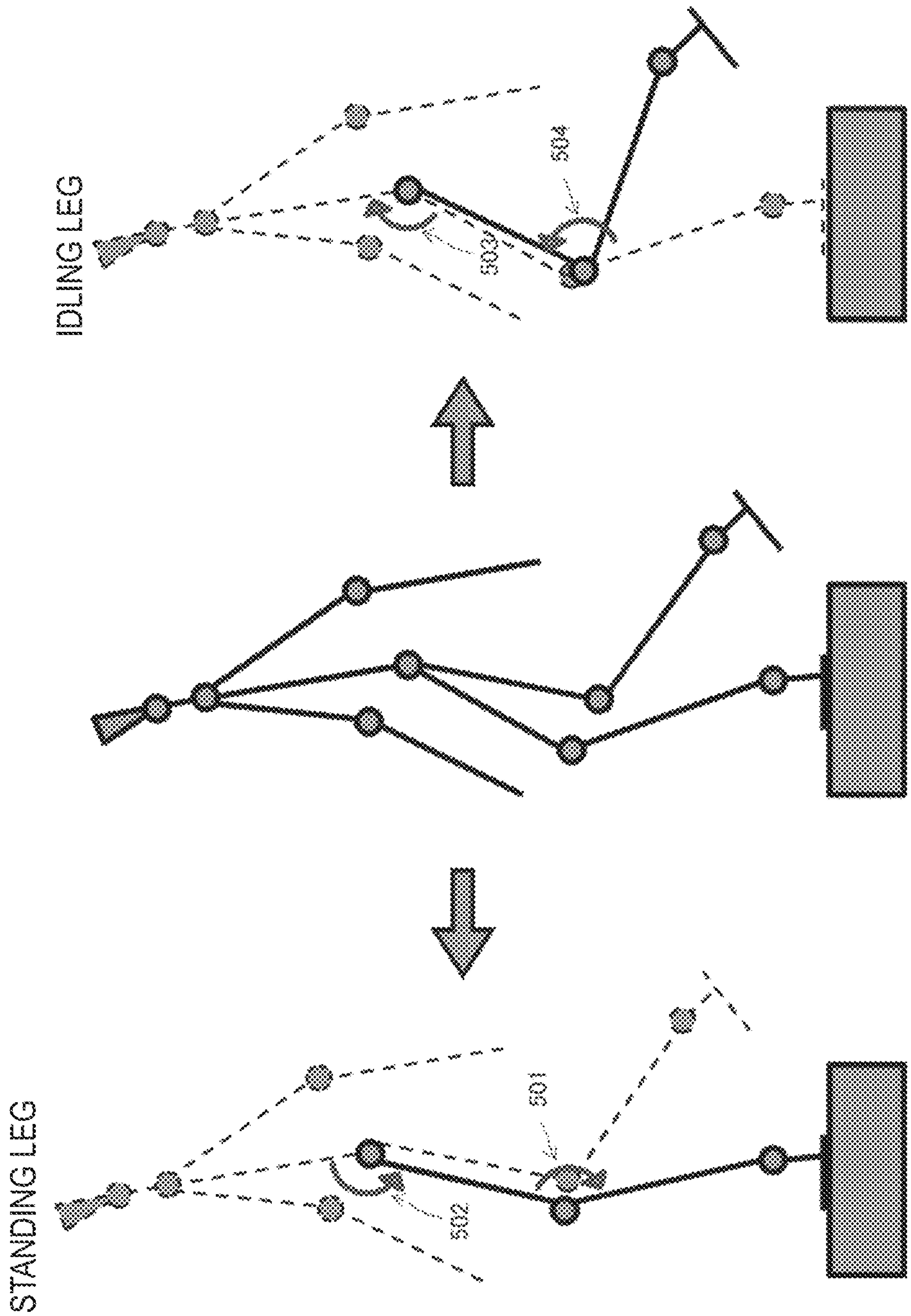


FIG. 6

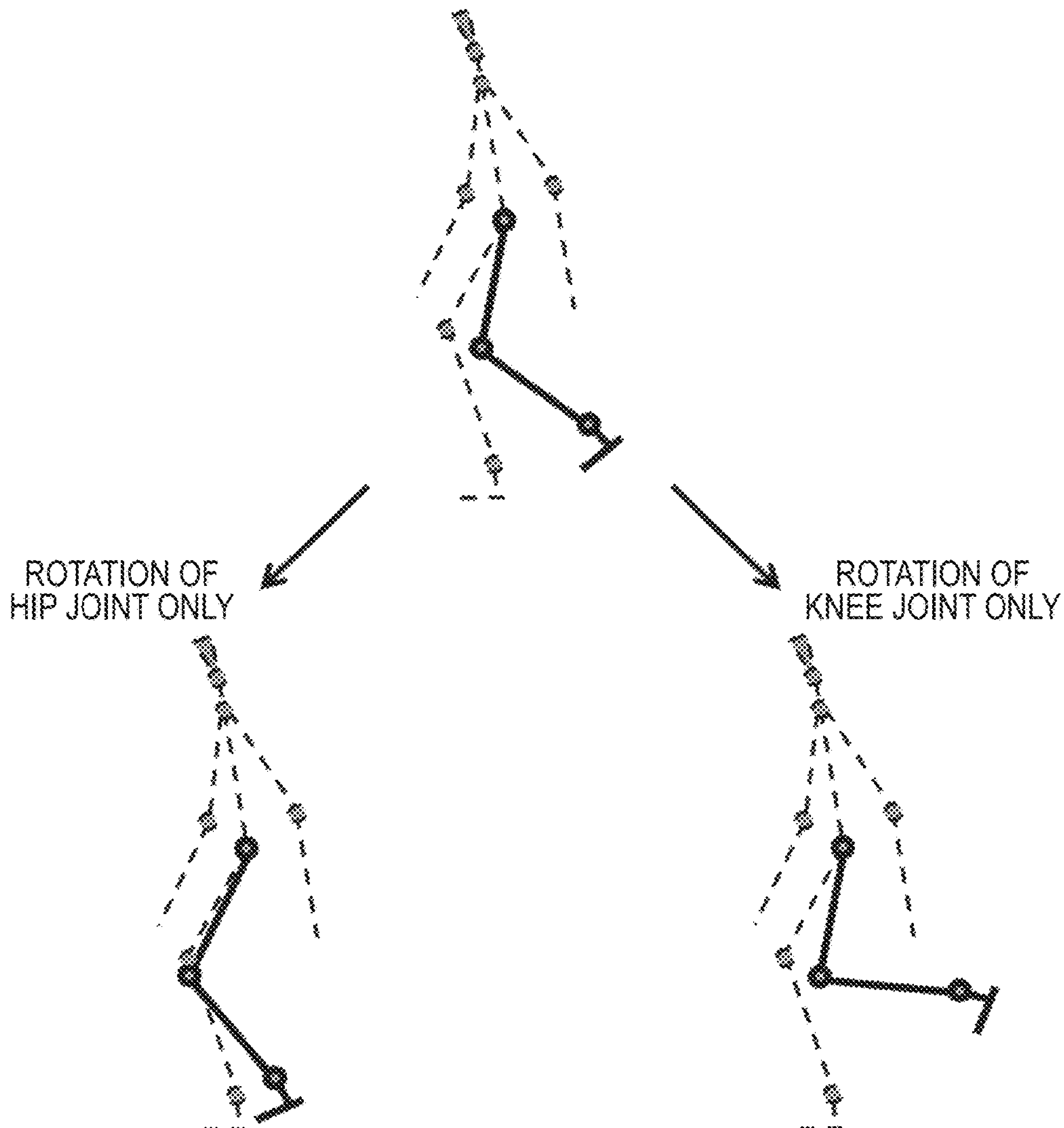


FIG. 7

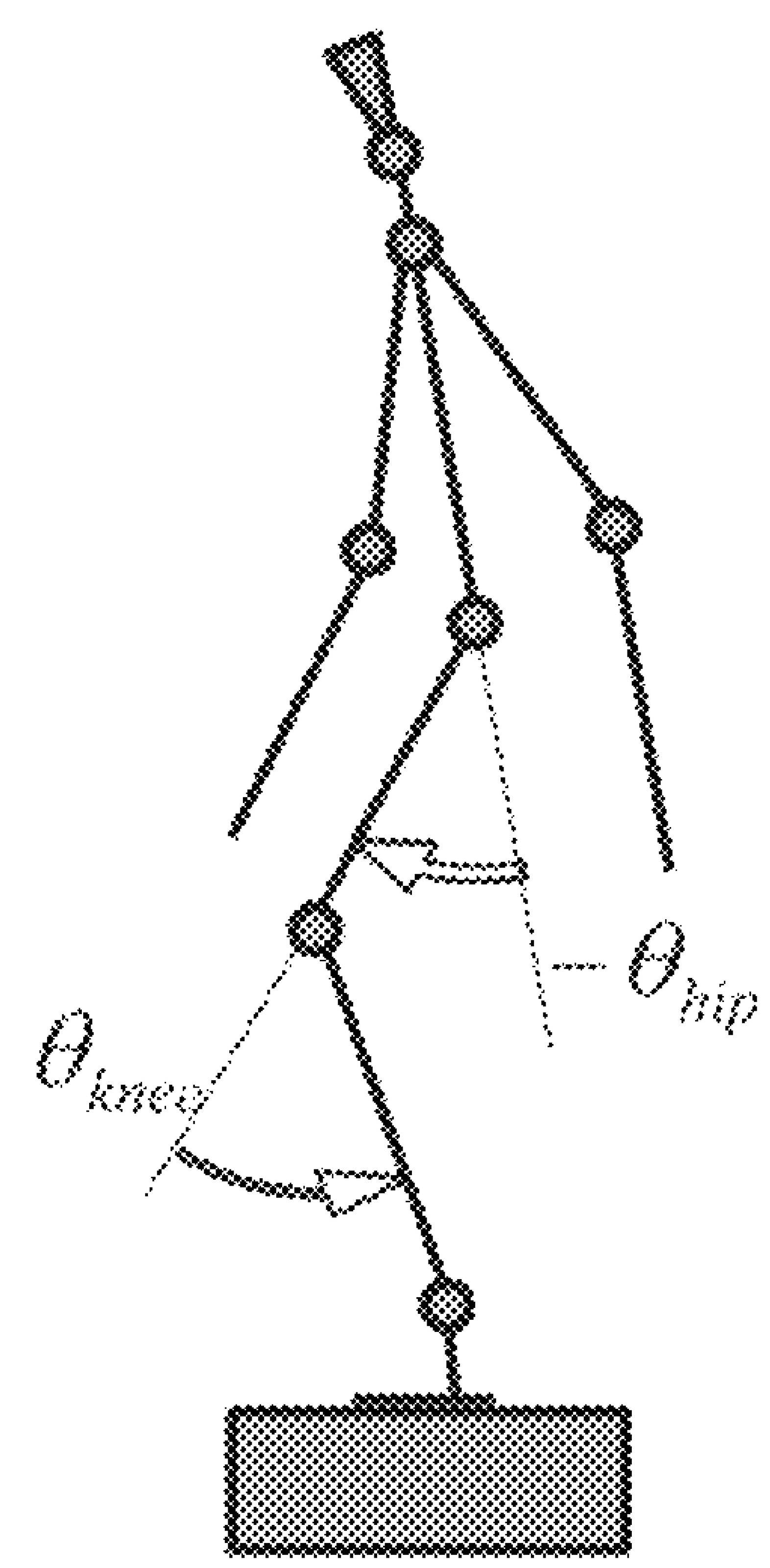


FIG. 8

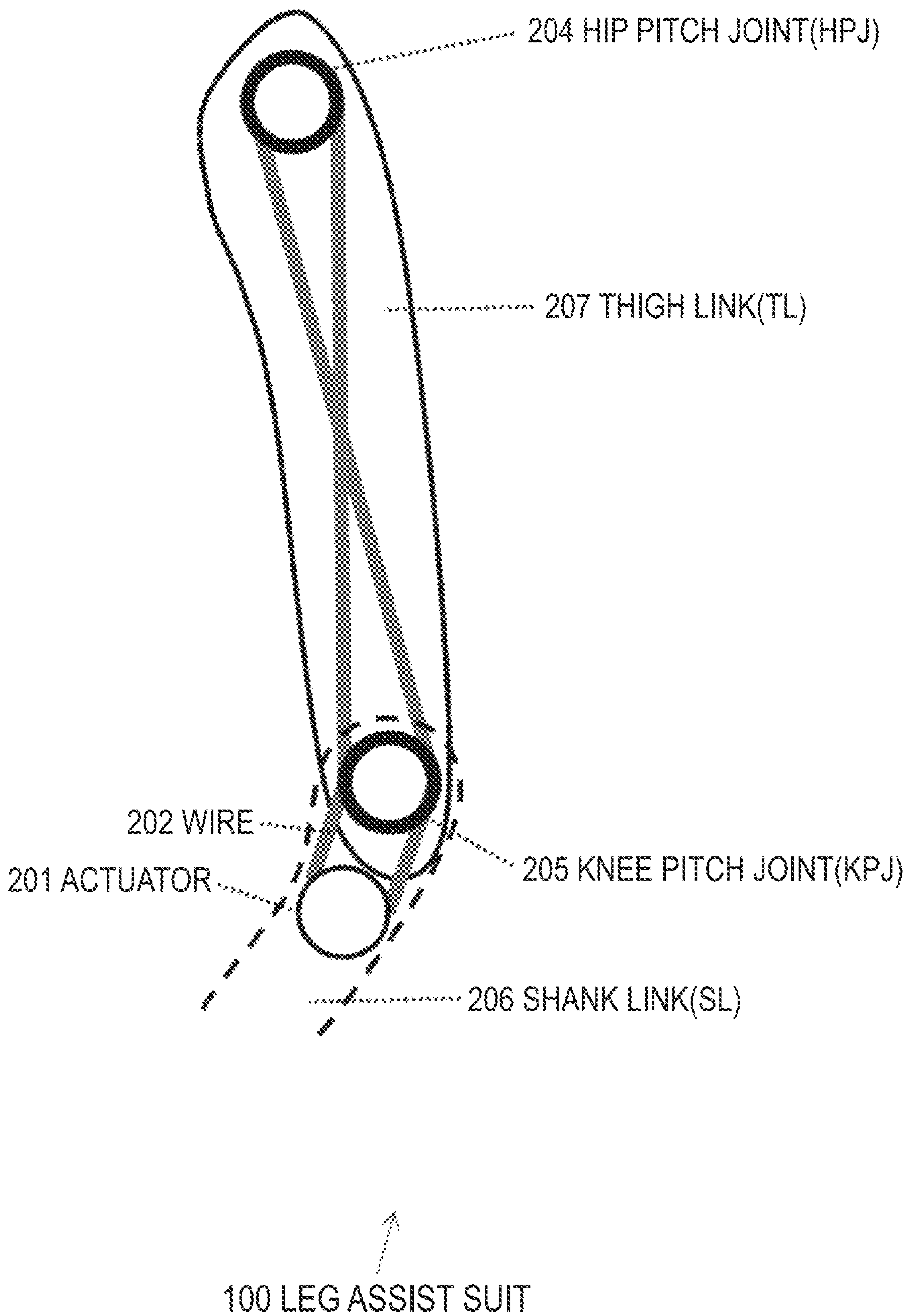

204 HIP PITCH JOINT(HPJ)
207 THIGH LINK(TL)
202 WIRE
201 ACTUATOR
205 KNEE PITCH JOINT(KPJ)
206 SHANK LINK(SL)
100 LEG ASSIST SUIT

FIG. 9

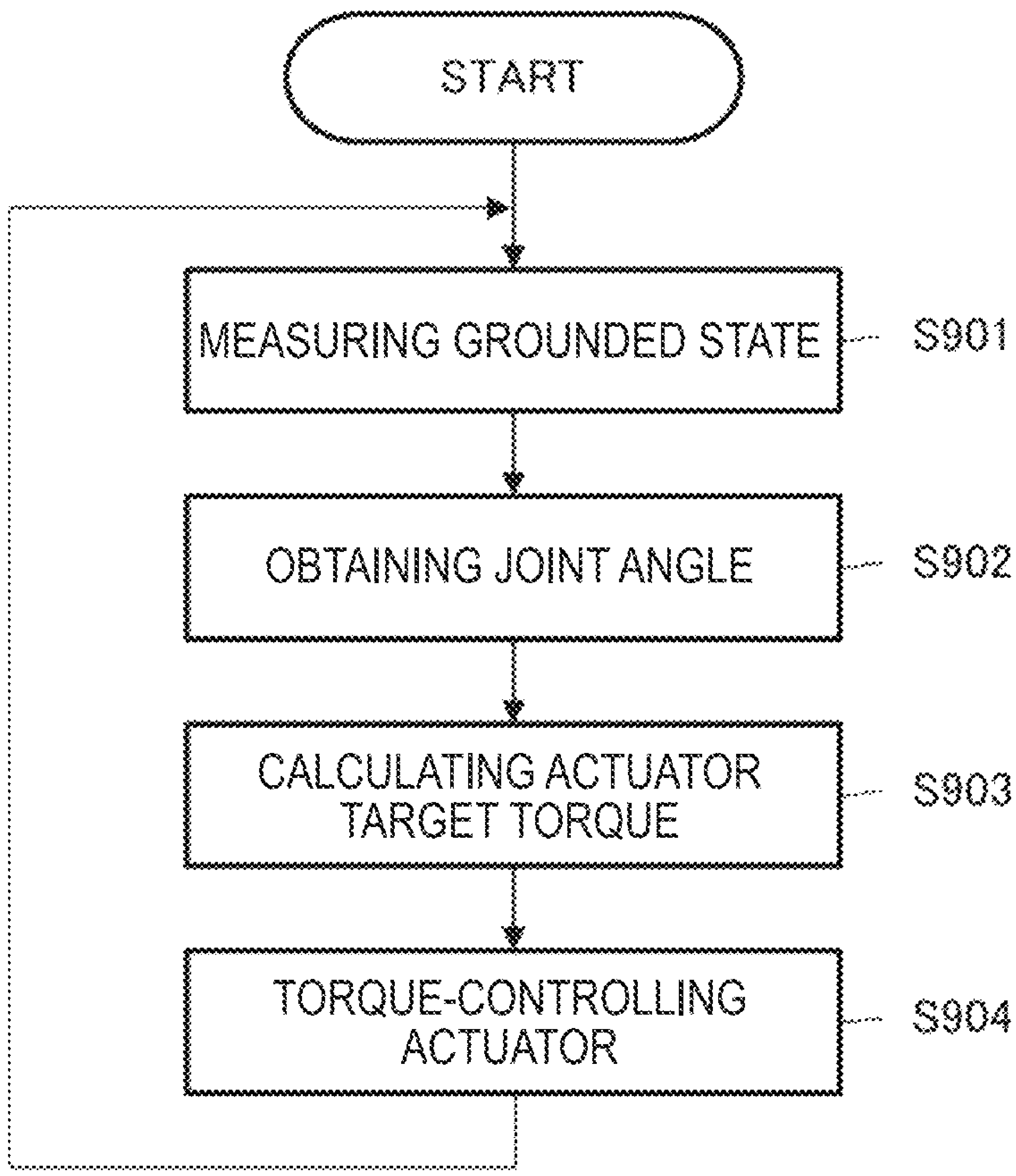
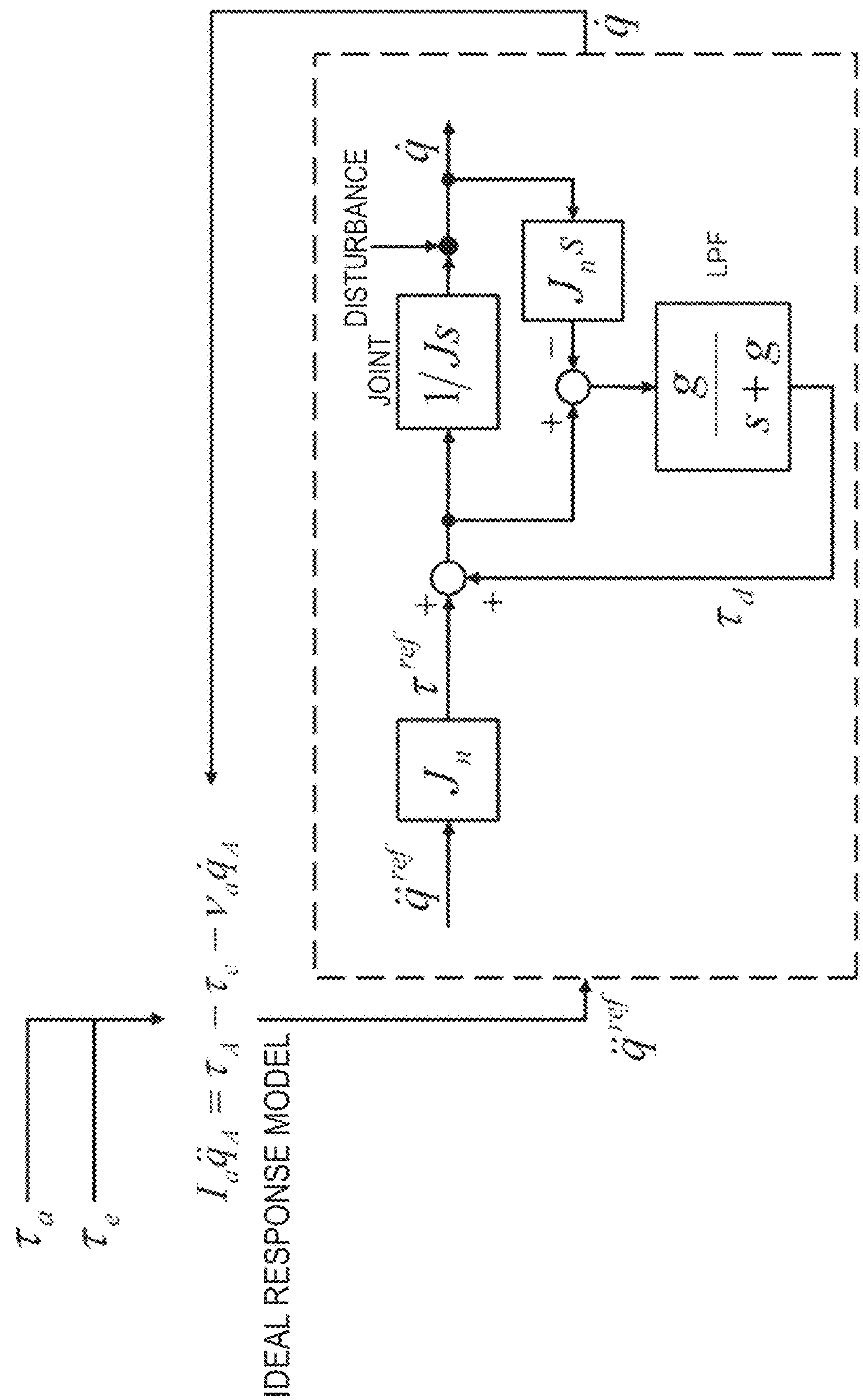

START
MEASURING GROUNDED STATE
S901
OBTAINING JOINT ANGLE
S902
CALCULATING ACTUATOR TARGET TORQUE
S903
TORQUE-CONTROLLING ACTUATOR
S904

FIG. 10


JOINT
DISTURBANCE
LPF
$1/Js$
$J_n s$
J_n
$\frac{g}{s+g}$
τ^{ref}
τ_d
$\ddot{q}^{ref}$
$\dot{q}$
τ_a
τ_e
$I_a \ddot{q}_A = \tau_A - \tau_e - v_a \dot{q}_A$
IDEAL RESPONSE MODEL

MOTION ASSIST DEVICE AND MOTION ASSIST METHOD

BACKGROUND

The technology of the present disclosure relates to a motion assist device, which is worn on a body of a person, mainly an aged person, etc., who desires assistance and nursing care, to physically and psychologically assist motion of the person's body, and to a motion assist method, and particularly relates to a motion assist device and a motion assist method for generally assisting various motions of the person's body including walking motion.

Japan's population aging rate (a proportion of elderly persons aged 65 or over to the total population) was 23.1% in 2010, which is expected to reach 30% in 2025. With such a rapid increase in ratio of elderly persons in the population composition, it has become an urgent task to realize a society where elderly persons can live healthy and actively without falling into a condition of need for long-term care as far as possible, and even if they fell into the condition of need for long-term care, they are prevented from worsening as far as possible and can lead an independent life.

In the face of an aging society, there is a growing demand in nursing homes and households with elderly members for mechatronic devices intended to physically and mentally assist elderly persons. Beyond the physical assistance provided by an autonomous walking assist device, a power assist suit, etc., there is also a demand for mental assistance by an occupational therapy in which a robot is effectively incorporated.

One of the important considerations in the development of assist/nursing-care mechatronic devices is to maintain and promote activities of elderly persons to the extent possible without unnecessary interference. If activities of the elderly persons are excessively performed by the machine just because they have declined in strength, the strength of the elderly persons will further decline, making the situation worse (disuse syndrome). The power assist suit, which is a device that applies an artificial force as assistance to a force generated by human muscles, is a desirable device in that it can maintain activities of the elderly person while supplementing the decreased strength of the elderly person.

However, at present the penetration rate of the power assist suit is still low. The following are the probable reasons.

(1) The power assist suit is troublesome to wear;
(2) It is expensive;
(3) The device is heavy;
(4) It gives support only in an awkward manner;
(5) It looks clumsy when worn; and
(6) The operating time is short.

For example, a force-control-type power assist method, which applies a driving force to joints on the basis of outputs from a myoelectric sensor and estimation results of motion phases, has recently been drawing attention (see e.g., Kawamoto H., Lee S., Kanbe S., Sankai Y.: "Power Assist Method for HAL-3 using EMG-based Feedback Controller", Proc. of Intl Conf. on Systems, Man and Cybernetics (SMC2003), pp. 1648-1653, 2003). However, since as much as nine myoelectric sensors have to be attached to one leg, they are troublesome to wean In addition, the myoelectric sensor can come off the skin due to temporal change or perspiration. Once the contact between the myoelectric sensor and the skin is lost, output values of the myoelectric sensor become unstable, which may cause the power assist suit to go out of control or an improper force to be applied to the body of the person wearing the suit.

Further, there has been proposed a walking assist device which applies a designed torque pattern in accordance with a phase of walking to a person's body while the person is walking (see e.g., Kenta Suzuki, Gouji Mito, Hiroaki Kawamoto, Yasuhisa Hasegawa, Yoshiyuki Sankai: "Intention-Based Walking Support for Paraplegia Patients with Robot Suit HAL", Advanced Robotics, Vol. 21, No. 12, pp. 1441-1169, 2007). However, since users walk in various patterns, there are many cases which are not covered by the designed torque patterns. For this reason, the walking assist device is likely to cause a sense of discomfort during walking or be capable of only unnatural, low speed walking.

On the other hand, there has been also proposed a body assist device which uses no myoelectric sensors (e.g., see J. Chan, R. Steger, Kazerooni, H., "Control and System Identification for the Berkeley Lower Extremity Exoskeleton", Advanced Robotics, Volume 20, Number 9, pp. 989-1011, Number 9, 2006). This device is configured to sense motion of a user's joint and apply a force for supporting the motion to the joint. However, this device unfortunately fails to reflect an intention of the user's motion with high sensitivity in the presence of an obstacle to the motion of the user's joint. For example, viscosity resistance at a gear part included in the joint units of the current power assist suit can cause an obstacle to the motion of the user's joint. Such an obstructive factor has to be eliminated in the future.

Most of the power assist suits which use no myoelectric sensors generate a force on the basis of an empirical rule or an invalid control law. Ideally, the myoelectric sensor can directly reflect an intention of the user's motion (although in reality, as mentioned above, stable sensing is hard to achieve with the myoelectric sensor). On the other hand, it is difficult to extract intentions of the user through sensing of the joint motion. Under these conditions, the present inventors consider that there has to be a valid control law for providing a supportive force without causing stress or a sense of unnaturalness to the user.

For example, there has been proposed a walking assist system which assists forward swing of a leg while supporting balance and a body weight of a user (see e.g., Japanese Patent Laid-Open No. 2011-62163). This walking assist system is constituted of an inverted-pendulum-type moving body for the user to grip and a walking assist device for assisting motion of the user's legs, and is configured such that a predetermined speed relationship is established between a target travelling speed of the inverted-pendulum-type moving body and that of the walking assist device. The inverted-pendulum-type moving body controls the travel on the basis of the target travelling speed and movement of a base body when the user grips the moving body, while the walking assist device transmits a force to the user on the basis of motion of the user's leg and the target travelling speed. Thus, the walking assist system can be considered to be a system which provides rhythm assistance, that is, supports a hip joint in accordance with a phase of walking. However, assistance of the walking assist system is applicable to walking motion and it is not versatile enough to be applied to other motions of the person's body. Additionally, a body weight assist having a saddle at a crotch part has also been proposed, but it gets in the way of sitting down and has an unattractive appearance.

The power assist suit in related art generally includes one actuator for driving of each joint. Accordingly, assisting more joint portions results in increasing the number of the actuators, which causes the device to become heavier, more expensive, and hence less practical. In addition, the high proportion of the actuators in the device restricts the design, so that the device tends to be visually unappealing, and contributes to shorter operating time due to increase of driving power.

SUMMARY

According to an embodiment of the present technology, there is provided an excellent motion assist device, which is worn on a body of a person, mainly an aged person, etc., who wants assistance and nursing care, and which can physically and psychologically assist motion of the person's body in a suitable manner, and a motion assist method.

According to an embodiment of the present technology, there is further provided an excellent motion assist device, which supports a force in a natural manner using a smaller number of actuators relative to a number of joints, while realizing reduction in weight and price, and a motion assist method.

According to an embodiment of the present technology, there is provided a motion assist device including a jth link worn on a jth portion of a user, an ith joint unit connected at one end of an ith link in a freely rotatable manner, a (j+1)th link worn on a (j+1)th portion of the user, an (i+1)th joint unit integral with one end of the (j+1)th link and coupled to the other end of the jth link, a single actuator installed at one of the jth link and a link adjacent to the jth link, and a transmission part transmitting a driving force of the actuator to the ith joint unit and the (j+1)th joint unit.

According to an embodiment of the present technology, the transmission part may transmit the driving force of the actuator in a manner that a proportional relationship is established between a torque generated at the ith joint unit and a torque generated at the (i+1)th joint unit.

According to an embodiment of the present technology, the transmission part may transmit the driving force of the actuator in a manner that driving directions of the ith joint unit and the (i+1)th joint unit are opposite to each other.

According to an embodiment of the present technology, the transmission part may transmit the driving force of the actuator to the ith joint unit and the (i+1)th joint unit through a wire,

According to an embodiment of the present technology, the transmission part constituted of the wire may be crossed between the ith joint unit and the (i+1)th joint unit.

According to an embodiment of the present technology the jth link may be a thigh link worn on a thigh part of a leg of the user. The ith joint unit may be a hip pitch joint connected at an upper end of the thigh link in a freely rotatable manner. The (j+1)th link may be a shank link worn on a shank part of the leg. The (i+1)th joint unit may be a knee pitch joint integral with an upper end of the shank link and coupled to a lower end of the thigh link. The actuator may be installed at the thigh link.

According to an embodiment of the present technology; the transmission part may include a wire which is wound around an output axis of the actuator, thereafter wound around the hip pitch joint in a same direction as a rotation direction of the actuator, and then wound around the knee pitch joint in an opposite direction to the rotation direction of the actuator.

According to an embodiment of the present technology, the jth link may be a thigh link worn on a thigh part of a leg of the user. The ith joint unit may be a knee pitch joint connected at a lower end of the thigh link in a freely rotatable manner. The (j+1)th link may be a pelvis link worn on the thigh part of the leg. The (i+1)th joint unit may be a hip pitch joint integral with the pelvis link and coupled to an upper end of the thigh link. The actuator may be installed at a shank link adjacent to the thigh link.

According to an embodiment of the present technology, the transmission part may include a wire which is wound around an output axis of the actuator, thereafter wound around the knee pitch joint in a same direction as a rotation direction of the actuator, and then wound around the hip pitch joint in an opposite direction to the rotation direction of the actuator.

According to an embodiment of the present technology, the motion assist device may further include a target torque determining part determining a torque target value of the actuator, and an actuator control part which controls the actuator by torque control on the basis of the torque target value.

According to an embodiment of the present technology, the motion assist device may further include a joint angle measuring part which measures a joint angle of the joint unit, and a torque measuring part which measures an external torque acting on the actuator. The actuator control part may control the actuator by torque control in a manner that a desired relationship is established between the joint angle measured by the joint angle measuring part and the external torque measured by the torque measuring part.

According to an embodiment of the present technology, the actuator control part may include a disturbance observer which calculates a disturbance torque τ_d at a time when the actuator is driven with a target torque τ_A. A joint angular acceleration target value may be obtained from an ideal response model of the actuator, in which the joint angular acceleration target value, which is achieved by the actuator responding on the basis of the target torque τ_A, an external torque τ_e, and a joint angle speed obtained by differentiating the joint angle by time, is calculated and output. The actuator control part may determine a command torque τ for the actuator in a current control period, by correcting a torque target value τ^{ref}, which is obtained by multiplying the joint angular acceleration target value by an inertia nominal value J_n in the actuator, with the disturbance torque τ_d, which is obtained by the disturbance observer in a previous control period.

According to an embodiment of the present technology, the motion assist device may further include a state detecting part which detects whether the leg is in a state of standing leg or an idling leg, a joint angle measuring part which measures joint angles of the hip pitch joint and the knee pitch joint, and a target torque determining part which determines the torque target value based on the joint angle of the hip pitch joint or the knee pitch joint depending on whether the leg is in the state of the standing leg or the idling leg. The actuator control part controls the actuator by torque control on the basis of the torque target value.

According to an embodiment of the present technology, the target torque determining part may determine the torque target value on the basis of the joint angle of the knee pitch joint when the leg is the standing leg, and determines the torque target value based on the joint angle of the hip pitch joint when the leg is the idling leg.

According to an embodiment of the present technology, the state detecting part may include a contact switch which determines whether or not a foot part of the leg is grounded.

According to an embodiment of the present technology, a motion assist method is for assisting motion of the user using the motion assist device, and includes detecting whether the leg is in a state of the standing leg or the idling leg, measuring joint angles of the hip pitch joint and the knee pitch joint, determining the torque target value based on the joint angle of the hip pitch joint or the knee pitch joint depending on whether the leg is in the state of the standing leg or the idling leg, and controlling the actuator by torque control on the basis of the torque target value.

According to the technology of the present disclosure, it is possible to provide the excellent motion assist device, which is configured to apply a force to the multiple joints by one actuator and thereby realizes reduction in weight and price, and the motion assist method.

Further, according to the technology of the present disclosure, it is possible to provide the excellent motion assist device, which can drive both the hip joint and the knee joint by one actuator by performing wire-coupled driving such that a certain relationship is established particularly between the hip joint and the knee joint, and which can realize reduction in weight and price without sacrificing natural manner of providing a supportive force by producing effects for supporting weight of the standing leg as well as for pulling up the idling leg, and the motion assist method.

Since a power assist suit to which the technology of the present disclosure is applied has a lower proportion of the actuator in the device, design for visual appeal is facilitated, and due to saving on the driving power for the actuator, the operating time can be increased.

Other purposes, features, and advantages of the technology of the present disclosure will be clarified by a detailed description based on the following embodiments and appended drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a schematic view showing a configuration of a leg assist suit **100** to which e technology of the present disclosure is applied;

FIG. **2** is an enlarged view around a hip joint and a knee joint of the leg assist suit shown in FIG. **1** (an example configuration where an actuator **201** is installed at a thigh link **207**);

FIG. **3** is a view showing an example configuration of an actuator (A) which is applied to joint driving of the leg assist suit shown in FIG. **1**;

FIG. **4** is a diagram of an example configuration of a control system of the leg assist suit **100** which is built around a host computer **203**;

FIG. **5** is a view showing a state where the leg assist suit **100** shown in FIG. **1** generates a supporting force to legs on a standing leg side and an idling leg side;

FIG. **6** is a view showing a state where the leg assist suit **100** shown in FIG. **1** generates the supporting force to the legs on the standing leg side and the idling leg side;

FIG. **7** is a view showing a bending/stretching angle θ_{knee} of the knee joint on the standing leg side and a bending angle θ_{hip} of the hip joint on the idling leg side;

FIG. **8** is an enlarged view around the knee joint and the hip joint of the leg assist suit shown in FIG. **1** (an example configuration where the actuator **201** is installed at a shank link **206**);

FIG. **9** is a flow chart showing a procedure for providing a supportive force to a user wearing the leg assist suit **100**; and

FIG. **10** is a control block diagram for realizing an ideal response of the actuator **201**.

DETAILED DESCRIPTION OF THE EMBODIMENT(S)

Hereinafter, preferred embodiments of the present disclosure will be described in detail with reference to the appended drawings. Note that, in this specification and the appended drawings, structural elements that have substantially the same function and structure are denoted with the same reference numerals, and repeated explanation of these structural elements is omitted.

FIG. **1** is a schematic view showing a configuration of a leg assist suit **100** to which the technology of the present disclosure is applied.

The illustrated leg assist suit **100** has total eight degrees of freedom: three degrees of freedom, roll, pitch, and yaw at a hip joint, and one degree of freedom, pitch at a knee joint, for each of left and right legs of a person's body. In FIG. **1**, joint units and links on the right side of the body are depicted with a solid line on the near side of the figure, while the joint units and the links on the left side of the body behind the right leg are depicted with a dotted line on the far side of the figure.

The joints are connected to each other by a rigid link. Specifically, left and right hip joints are connected by a pelvis link (PL) **208**; the hip joint and a knee joint on each of the left and right sides are connected by a thigh link (TL) **207**; and the knee joint and an ankle joint on each of the left and right sides are connected by a shank link (SL) **206**. The pelvis link (PL) **208**, the thigh link **207**, and the shank link **206** are each fixed to the person's body by a band (not shown).

The leg assist suit **100** illustrated has, in each of the left and right legs, four degrees of joint freedom of a hip yaw joint (HYJ) **209**, a hip roll joint (HRJ) **210**, a hip pitch joint (HPJ) **204**, and a knee pitch joint (KPJ) **205**. Of these joints, only the hip pitch joint **204** and the knee pitch joint **205** are active joints which generate a driving force, and the other hip yaw joint **209** and the hip roll joint **210** are free joints which do not generate a force. In addition, the ankle joint is only fixed by the band and there is no freedom at the ankle joint.

A host computer **203** which controls the leg assist suit **100** is mounted on the pelvis part. Contact sensors (footSW) **211** for detecting a grounded state between a foot bottom and a road surface are mounted on the left and right foot bottom parts, and whether each of the left and right legs is in a state of a standing leg or an idling leg can be determined on the basis of outputs of the contact sensor **211**.

FIG. **2** is an enlarged view around the hip joint and the knee joint of the leg assist suit **100** shown in FIG. **1**. As illustrated, the hip pitch joint **204** and the knee pitch joint **205** on each of the left and right sides are the active joints, and these joints are driven by one actuator **201**. This actuator **201** is installed at the thigh link **207**, and outputs thereof are transmitted through a wire **202** to the hip pitch joint **204** and the knee pitch joint **205**. Although the actuator is not provided at the left and right knee pitch joints **205**, an encoder (not shown in FIG. **2**) which measures a joint angle θ_{knee} of the knee pitch joint **205** is separately mounted on the knee pitch joints.

In the example shown in FIG. **2**, the wire **202** is wound around an output axis of the actuator **201**, thereafter wound around the hip pitch joint **204** in the same direction as a rotation direction of the actuator **201**, namely in a regular direction, and then wound around the knee pitch joint **205** in an opposite direction to the rotation direction of the actuator

201, namely in a non-regular direction. The wire **202** is crossed between the hip pitch joint **204** and the knee pitch joint **205**.

The knee pitch joint **205** is fixed to the shank link **206**. Specifically, a pulley of the knee pitch joint **205** is formed integrally with the shank link **206**. Thus, when rotation of the output axis of the actuator **201** is transmitted through the wire **202** to the knee pitch joint **205**, the shank link **206** operates integrally with the knee pitch joint **205**.

On the other hand, the hip pitch joint **204** is freely attached to the thigh link **207**. Specifically, a pulley of the hip pitch joint **204** is not integral with the thigh link **207** but freely rotatable through a bearing (not shown). Thus, rotation of the output axis of the actuator **201** alone does not cause the thigh link **207** to be operated through the pulley of the hip pitch joint **204**, and a torque τ_{hip} is not generated at the hip pitch joint **204**.

Here, when a torque τ_{knee} is generated at the knee pitch joint **205**, which is integral with the shank link **206**, by an external force applied to the ankle, etc., a coupled torque τ_{hip} is generated at the hip pitch joint **204** due to the coupled driving through the wire **202** (see K. Yokoi et W. "Design and Control of a Seven-Degrees-of-Freedom Manipulator Actuated by a Coupled Tendon-Driven System", In Proc. Annual Conf. of Robotics Society of Japan, 1991, pp. 461-464). As described later, a proportional relationship is established between the torque τ_{hip} generated at the hip pitch joint **204** and the torque τ_{knee} generated at the knee pitch joint **205**.

Thus, since there is a restraining relationship through wire-coupled driving between the hip pitch joint **204** and the knee pitch joint **205**, the knee part and the thigh part of the leg assist suit **100** can be simultaneously operated using the single actuator **201** alone.

FIG. **3** shows an example configuration of the actuator **201** which is applied to simultaneous driving of the hip pitch joint **204** and the knee pitch joint **205** of the leg assist suit **100** shown in FIG. **1**. The actuator **201** illustrated includes a motor **300** main body constituted of a rotor **301** and a stator **302**, and a speed reduction part **303** constituted of a gear such as a wave gear device, and the actuator is mounted on an interface substrate **304**. An encoder **305** which detects rotational positions, namely angles of the joints, is attached to the rotor of the motor. In addition, a link of a subsequent stage (not shown) is connected through a bearing **306** to the output axis of the speed reduction part, and a torque sensor **307** for detecting an output torque is attached to the output axis.

The hip pitch joint **204** has the wire **202** wound around it same direction as the rotation direction of the actuator **201**. Thus, a joint angle θ_{hip} of the hip pitch joint **204** can be measured by the output of the encoder **305** inside the actuator **201**. In addition, the joint angle θ_{knee} of the knee pitch joint **205** can be measured by the (above-mentioned) encoder which is separately attached to the knee pitch joint **205**.

FIG. **4** shows an example configuration of a control system for the leg assist suit **100** which is built around the host computer **203** mounted on the pelvis part of the leg assist suit **100**. Actuators **201**L/R respectively provided on the left and the right sides are provided with microcomputers **401**L/R for performing torque control and communication with the host computer **203**. The host computer **203** can give a torque control target value to the motor **300** inside the actuator **201** through the microcomputers **401**L/R. Further, the host computer **203** can read out detected values of encoders **305**L/R and torque sensors **307**L/R included in the actuator **201**L/R through the microcomputers **401**L/R. In addition, encoders **403**L/R at the left and right knee joints are provided with microcomputers **402**L/R, respectively, and contact sensors **211**L/R mounted on the left and right foot bottoms are also provided with microcomputers **404**L/R, respectively. The host computer **203** can read out outputs of the encoders **403**L/R and the contact sensors **211**L/R of the left and right feet through the microcomputers **402**L/R and **404**L/R by similar communication.

The host computer **203** can obtain the joint angle θ_{hip} of the hip pitch joint from the output value of the encoders **305**L/R inside the actuator **201**L/R, and can obtain the joint angle θ_{knee} of the knee pitch joint from the output value of the encoders **403**L/R at the knee joint.

In the present embodiment, the host computer **203** adopts not a position control method but a force control method for the actuator **201**, and performs force control, without using myoelectric sensors, on the basis of the joint angle θ_{hip} of the hip pitch joint **204** and the joint angle θ_{knee} of the knee pitch joint **205** which are equivalent to motion of the user's joints. Thus, the user is relieved of the trouble of wearing the myoelectric sensors onto the body, and freed from the danger of malfunction based on instability of output values of the myoelectric sensor.

These joint units involve factors such as friction and inertia which cause large errors and are difficult to model or identify. Therefore, in order to realize an ideal joint unit (IJU), such an actuator control device is used for driving the actuator **201** that can deal with disturbance factors existing at the joint units such as friction and inertia, which are difficult to model or identify, and can instruct an output torque on the basis of a mathematical model (ideal response model). Specifically, precise response based on the mathematical model is realized by controlling the actuator **201** using the values of the torque sensor **307** and the outputs of the encoder **305** (see e.g., Japanese Patent No. 4715863). The actuator **201** shows precise secondary-system response, which is governed by specified inertia and viscosity resistance, to the command torque and the external torque. This prevents the motion of the joints from being hindered by friction in the gear of the speed reduction part, etc., and allows even a slight force acting on the joint to be precisely represented as a change in angular acceleration of the actuator **201**. Thus, the precise response based on the mathematical model can be realized by controlling by means of the output torque obtained by the torque sensor **307** and the angle detected by the encoder **305**. Accordingly, it is possible to generate a force for supporting motion of the user wearing the leg assist suit **100** without causing resistance to the joint of the user.

Assuming that mass properties of the leg assist suit **100** shown in FIG. **1** and the person wearing it are known, when a system combining the person and the leg assist suit is modeled as a two-legged robot, the actuator **201** in its dynamics operation is modeled by the following Expression (1).

$$I_a\ddot{q}_A=\tau_A-\tau_e-v_a\dot{q}_A \tag{1}$$

In the above Expression (1), I_a denotes a virtual inertia; q_A denotes a joint angle of the joint (equivalent to θ_{hip} and θ_{knee} obtained as the outputs of the encoder); τ_A denotes a torque target value which is a command value of a torque generated at the joint; τ_e denotes an external torque acting on the joint; and v_a denotes a virtual viscosity coefficient inside the joint (unknown and difficult to model). A calculation method of the torque target value τ_A will be described later.

Expression (1) shows that the ideal model includes the external torque term τ_e acting on the joint. Thus, in order to correct the response of the actuator **201** to follow the ideal model, this external torque τ_e is desired to be detected. In the present embodiment, as described above, the actuator **201** is provided with the torque sensor **307** (see FIG. **3**) for measuring the external torque τ_e at the output axis of the speed reduction part **303**, and the torque measurement results are collected in the host computer **203**.

That the actuator **201** responds in accordance with the ideal model represented by the above Expression (1) means exactly that, when the right side of the above Expression (1) is given, the joint angular acceleration on the left side is achieved. By applying a disturbance observer, which estimates the disturbance torque, to the configuration of such a control system for joint angular acceleration, the joint torque τ can be determined with high accuracy on the basis of the ideal response model.

FIG. **10** shows a control block diagram for realizing the ideal response of the actuator **201**. In the same figure, a portion enclosed by the dotted line corresponds to the disturbance observer, which estimates the disturbance torque τ_d and eliminates its influence on the control system, thereby establishing a robust acceleration control system. Here, J_n denotes a nominal value of inertia in the joint; J denotes an (unknown) actual value of the inertia in the joint; and q_A denotes the joint angle. In addition, the virtual inertia I_a of the joint is given a virtual constant number as a design matter in the dynamics operation.

In the host computer **203**, the target torque τ_A which is the command value to the actuator **201** is determined for each control period by the force control method, and the external torque actual measurement value τ_e measured by the torque sensor **307** attached to the output axis of the speed reduction part **303** of the actuator **201**, and an angle speed actual measurement value obtained from the joint angle q_A measured by the encoder **305**, etc., are sent from the microcomputer **401** provided in the actuator **201** to the host computer **203**. Then, these target torque τ_A, an external torque actual measurement value τ_e, and the angle speed actual measurement value of the joint angle q_A are substituted into the ideal response model represented by the above Expression (1) to obtain the acceleration target value for the joint angle q_A on the left side of the same expression, and this angular acceleration target value is input to the disturbance observer.

In the disturbance observer, the input acceleration target value of the joint angle q_A is multiplied by the virtual inertia nominal value J_n of the joint, and converted into a torque target value τ^{ref} for the current control period. Then, the torque target value τ^{ref} is corrected with the disturbance torque τ_d, which is obtained by the disturbance observer in a previous control period, to obtain the torque command value τ for the joint in the current control period.

When force control constituted of the torque command value τ is applied to the joint having a transfer function $1/J_n$, the joint is rotary driven under the influence of the disturbance such as friction and inertia existing in the joint unit. Specifically, the torque command value τ is converted into a current command value, which becomes an instruction input to a driving circuit of the motor **300**. The torque τ_e generated at this time and the joint angle q_A are measured by the torque sensor **307** and the encoder **305**, etc., respectively, and the joint angle output q_A is differentiated by time to obtain the joint angle speed.

The disturbance observer can estimate the torque which has acted on the joint by applying a transfer function $J_n s$ constituted of the virtual inertia nominal value J_n of the joint to the measured angle speed of the joint angle q_A, and can estimate the disturbance torque τ_d by subtracting this estimated torque from the torque command value τ for the joint. Then, the disturbance torque τ_d obtained in the current control period is fed back and used for correction of the torque command value τ in the next control period. The purpose of a low-pass filter (LPF) represented by g/(s+g) and inserted in the middle is to prevent the system from diverging.

In this way, even when disturbance components such as friction and inertia which are not able to be modeled exist in the joint unit, it is possible to have the acceleration response of the actuator to follow the acceleration target value. That is, since the joint angular acceleration on the left side of the above Expression (1) can be achieved when the right side is given, the actuator can respond in accordance with the ideal model despite being subjected to the influence of the disturbance. However, the disturbance observer is not suitable for elimination of disturbance in a high-frequency region, since the above-described low-pass filter g/(s+g) is inserted in the middle of the feedback of the disturbance torque τ_d (as described above).

The disturbance observer estimates the disturbance components in a plant and feeds back to a control input, thereby allowing a target condition to be reached even in the presence of an unknown parameter fluctuation and disturbance in the plant. However, in order to correctly estimate the disturbance, the feedback operation is desired to be repeated over multiple cycles.

In the control block configuration shown in FIG. **10**, the disturbance observer obtains the angular acceleration of the joint angle q_A from the above Expression (1), and sets it as the joint angular acceleration target value for the actuator of the joint unit. The angular acceleration of the joint angle q is determined on the basis of the external torque τ_e obtained from the torque sensor **307**, the target torque τ_A for the joint, and the time differentiation of the joint angle q_A output from the encoder **305**, etc. Due to such a configuration, the joint unit can respond in accordance with the inertia I_a and the viscosity coefficient v_a, and thereby idealized.

As described above, the wire **202** is wound around the output axis of the actuator **201**, thereafter wound around the hip pitch joint **204** in the same direction as the rotation direction of the actuator **201**, and then wound around the knee pitch joint **205** in the opposite direction to the rotation direction of the actuator **201** (see FIG. **2**). Due to coupled driving through this wire **202**, a torque as represented by the following Expression (2) is generated at each joint of the leg assist suit **100** (see. e.g., K. Yokoi et al., pp. 461-464).

$$\tau_i=\Sigma s_{ij} r_{ij} f_j \tag{2}$$

In the above Expression (2), τ_i denotes a torque generated at an ith joint, and f_j denotes a tensile force generated in a jth wire. The jth wire is wound around the ith joint by a pulley having a radius r_{ij}. In addition, s_{ij} indicates a direction in which the jth wire is wound around the pulley of the ith joint, with a plus or a minus sign. If the pulley rotates in a regular direction of the angle of the joint on which the tensile force f_j acts, s_{ij} has a value +1, and if the pulley rotates in the opposite direction, s_{ij} has a value −1.

An end of the jth wire is connected through a pulley having a radius R_j to the actuator which generates a torque τ_j represented by the following Expression (3).

$$\tau_j=f_j R_j \tag{3}$$

By the above Expressions (2) and (3), the torque generated at the ith joint is represented by the following Expression (4).

$$\tau_i=\Sigma s_{ij} r_{ij}/R_j \tau_j \tag{4}$$

Here, assuming that all the pulleys have equal radii, when applying the above Expression (4) to the example shown in FIG. **1**, the torque τ_{hip} and τ_{knee} as shown in the following Expressions (5) and (6) are generated at the hip joint and the knee joint, respectively.

$$\tau_{hip}\times 1.0\times\tau_A \tag{5}$$

$$\tau_{knee}=-1.0\times\tau_A \tag{6}$$

In the above Expressions (5) and (6), τ_A denotes a torque generated by the actuator **201** provided in the thigh part. The above Expressions (5) and (6) show that the torque generated by wire-coupled driving at the hip pitch joint **204** and the knee pitch joint **205** is equal in magnitude but opposite in direction. If the radii of the pulleys of the hip pitch joint **204** and the knee pitch joint **205** are not equal, the torque τ_{hip} and τ_{knee} are not equal in magnitude, but the torque is generated in the opposite direction at a constant ratio according to the ratio of the radii of the pulleys.

In the leg on (he standing leg side of the leg assist suit **100**, the knee pitch joint **205** operates so as to extend the thigh link **207** and the shank link **206** (see reference numeral **501** in FIG. **5**), and pushes up the user's body weight, which plays an important role in climbing up stairs, for example. It is preferable that, at the same time with this, the hip pitch joint **204** operates so as to extend the thigh link **207** with respect to the user's trunk (see reference numeral **502** in FIG. **5**) and maintains the posture of an upper body. In this case, the knee pitch joint **205** operates in the clockwise direction on the plane of FIG. **5**, while the hip pitch joint **204** operates conversely in the counterclockwise direction. Thus, in the state of the standing leg, the hip pitch joint **204** and the knee pitch joint **205** are in a cooperative relationship.

On the other hand, in the leg on the idling leg side, the hip pitch joint **204** operates so as to bend the thigh link **207** with respect to the user's trunk (see reference numeral **503** in FIG. **5**), and pulls up the user's idling leg. It is preferable that, at the same time with this, the knee pitch joint **205** operates so as to bend the thigh link **207** and the shank link **206** (see reference numeral **504** in FIG. **5**) so as to prevent a toe of the idling leg from hitting against the ground. In this case, the hip pitch joint **204** operates in the clockwise direction on the plane of FIG. **5**, while the knee pitch joint **205** operates conversely in the counterclockwise direction. Thus, in the state of the idling leg, the knee pitch joint **205** and the hip pitch joint **204** are in a cooperative relationship.

Even though the hip pitch joint **204** and the knee pitch joint **205** are in a cooperative relationship, it is necessary to configure the hip pitch joint **204** and the knee pitch joint **205** such that the angle of the hip pitch joint **204** and the knee pitch joint **205** can be independently changed so as to allow the idling leg (and the standing leg) to take any posture according to the user's intention (e.g., as shown in FIG. **6**, to operate the hip pitch joint only or operate the knee pitch joint only).

Due to the configuration as shown in FIG. **1**, even though the driving source is only one actuator **201**, the leg assist suit **100** can coordinate the two joints of the hip joint and the knee joint by torque control and coupled driving through the wire **202**, while allowing the joint angle to be changed independently. That is, as shown in FIG. **5**, the leg assist suit **100** can generate a supportive force for pushing up the body weight in the leg part on the standing leg side, and generate a supportive force for pulling up the leg in the leg part on the idling leg side. In FIG. **5**, the direction of torque generation indicates a direction of the torque acting from the link on a lower limb base (pelvis) side to the link on a lower limb end (foot bottom) side.

In the leg on the standing leg side, from a viewpoint of pushing up the user's body weight, the knee pitch joint **205** assumes more important role. In addition, in the leg on the idling leg side, from a viewpoint of pulling up the leg part, the hip pitch joint **204** assumes more important role. Therefore, as a possible force support law, a method such as the following can be considered: for the standing leg side, generating the torque τ_A of the actuator **201** according to the bending/stretching angle θ_{knee} of the knee joint (see the following Expression (7)), and for the idling leg side, generating the torque τ_A of the actuator **201** according to the bending angle θ_{hip} of the hip joint (see the following Expression (8)). The bending/stretching angle θ_{knee} of the knee joint on the standing leg side and the bending angle θ_{hip} of the hip joint on the idling leg side are. as shown in FIG. **7**.

$$\text{(Standing leg side) } \tau_A=K_{p1}(\theta_{knee}) \tag{7}$$

$$\text{(Idling leg side) } \tau_A=K_{p2}(\theta_{hip}) \tag{8}$$

FIG. **2** shows the example configuration where the single actuator **201** is installed at the thigh link **207** and the two joints of the hip pitch joint **204** and the knee pitch joint **205** are coupled-driven through the wire. In this example configuration, the wire **202** is wound around the hip pitch joint **204** in the same direction with the rotation direction of the output axis of the actuator **201**, and wound around the knee pitch joint **205** in the opposite direction to the rotation direction of the output axis of the actuator **201**, and the pulley of the knee pitch joint **205** is integral with the shank link **206**, while the pulley of the hip pitch joint **204** is freely rotatable with respect to the thigh link **207**.

By contrast, it is also possible to configure the leg assist suit **100** with the single actuator **201** installed at the shank link **206** instead of at the thigh link **207**. In the example shown in FIG. **8**, the wire **202** is wound around the output axis of the actuator **201** installed at the shank link **206**, thereafter wound around the knee pitch joint **205** in the same direction with the rotation direction of the actuator **201**, namely in the regular direction, and then wound around the hip pitch joint **204** in the opposite direction to the rotation direction of the actuator **201**, namely in the non-regular direction. The wire **202** is crossed between the knee pitch joint **205** and the hip pitch joint **204**.

The hip pitch joint **204** is fixed to the pelvis link **208**. Specifically, the pulley of the hip pitch joint **204** is formed integrally with the pelvis link **208**. Thus, when the rotation of the output axis of the actuator **201** is transmitted through the wire **202** to the hip pitch joint **204**, the thigh link **207** is operated with respect to the pelvis link **208**.

On the other hand, with respect to both the shank link **206** and the thigh link **207**, the knee pitch joint **205** is integral with neither of the free shank link **206** and thigh link **207** but freely rotatable through a bearing (not shown). Thus, the rotation of the output axis of the actuator **201** alone does not cause the shank link **206** to be operated through the pulley of the knee pitch joint **205**, and the torque τ_{knee} is not generated at the knee pitch joint **205**.

Here, when the torque τ_{hip} is generated at the hip pitch joint **204**, which is integral with the pelvis link **208**, by an external force applied to the pelvis link **208**, etc., the coupled torque τ_{knee} is generated at the knee pitch joint **205** due to the coupled driving through the wire **202** (same as above). As already described, a proportional relationship is established between the torque τ_{hip} generated at the hip pitch joint **204** and the torque τ_{knee} generated at the knee pitch joint **205**.

Thus, also in the example configuration shown in FIG. **8**, since there is a restraining relationship due to the wire-coupled driving between the hip pitch joint **204** and the knee pitch joint **205**, the leg assist suit **100** can simultaneously operate the knee part and the thigh part using the single actuator **201** alone.

It should be understood that the above-described force support law is valid in both of the leg part configurations shown in FIG. **2** and FIG. **8**. That is, for the standing leg side, generating the torque τ_A of the actuator **201** according to the bending/stretching angle θ_{knee} of the knee joint (see the above Expression (7)), and for the idling leg side, generating the torque τ_A of the actuator **201** according to the bending angle θ_{hip} of the hip joint (see the above Expression (8)).

FIG. **9** shows a procedure for providing a supportive force to the user wearing the leg assist suit **100** in a form of a flow chart. This procedure is realized, for example, by the host computer **203** executing a predetermined program code.

First, the host computer **203** reads out the output of the contact sensors **211**L/R mounted on the left and right foot bottoms through the microcomputers **404**L/R, and determines a grounded state of each of the left and right feet (S**901**).

Next, he host computer **203** reads out the output of the encoder **305**L/R included in the actuator **201**L/R through the microcomputers **401**L/R; reads out the output of the encoder **403**L/R of the left and right knee joints through the microcomputers **402**L/R; and obtains joint angle θ_{hip} of the hip joint and the joint angle θ_{knee} of the knee angle on the left and the right sides (S**902**).

Thereafter, the host computer **203** calculates the torque target values for the actuator **201**L/R for each of the left and right legs on the basis of the above Expressions (7) and (8) (S**903**).

Then, the host computer **203** gives the torque target value obtained in the process S**903** to the motor **300** inside the actuator **201** through the microcomputers **401**L/R (S**904**).

By executing the above procedure in each control period of, for example, 10 milliseconds, the leg assist suit **100** can provide a supportive force in a natural manner to motion such as walking of the user wearing it.

The leg assist suit **100** according to the present embodiment is configured to apply a force to the multiple joints by the single actuator **201**, and thereby can realize reduction in weight and price. In particular, by performing wire-coupled driving such that a certain relationship is established between the hip pitch joint **204** and the knee pitch joint **205**, the leg assist suit **100** can produce effects for supporting weight of the standing leg and for pulling up the idling leg, and can realize reduction in weight without sacrificing the natural manner of providing a supportive force.

It should be understood by those skilled in the art that various modifications, combinations, sub-combinations and alterations may occur depending on design requirements and other factors insofar as they are within the scope of the appended claims or the equivalents thereof.

Additionally, the present technology may also be configured as below

(1) A motion assist device including:

a jth link worn on a jai portion of a user;

an ith joint unit connected at one end of an ith link in a freely rotatable manner;

a (j+1)th link worn on a (j+1)th portion of the user;

an (i+1)th joint unit integral with one end of the (j+1)th link and coupled to the other end of the jth link;

a single actuator installed at one of the jth link and a link adjacent to the jth link; and

a transmission part transmitting a driving force of the actuator to the ith joint unit and the (i+1)th joint unit.

(2) The motion assist device according to (1),

wherein the transmission part transmits the driving force of the actuator in a manner that a proportional relationship is established between a torque generated at the ith joint unit and a torque generated at the (i+1)th joint unit.

(3) The motion assist device according to (1),

wherein the transmission part transmits the driving force of the actuator in a manner that driving directions of the ith joint unit and the (i+1)th joint unit are opposite to each other.

(4) The motion assist device according to (1),

wherein the transmission part transmits the driving force of the actuator to the ith joint unit and the (i+1)th joint unit through a wire.

(5) The motion assist device according to (4),

wherein the transmission part constituted of the wire is crossed between the ith joint unit and the (i+1)th joint unit.

(6) A motion assist device including:

a thigh link worn on a thigh part of a leg of a user;

a hip pitch joint connected at an upper end of the thigh link in a freely rotatable manner;

a shank link worn on a shank part of the leg;

a knee pitch joint integral with an upper end of the shank link and connected to a lower end of the thigh link;

an actuator installed at the thigh link; and

a transmission part transmitting a driving force of the actuator to the hip pitch joint and the knee pitch joint.

(7) The motion assist device according to (6) above, wherein the transmission part transmits the driving force to the hip pitch joint in the same direction as a driving direction of the actuator, and transmits the driving force to the knee pitch joint in an opposite direction to the driving direction of the actuator.

(8) The motion assist device according to (6) above, wherein the transmission part is constituted of a wire wound around an output axis of the actuator, thereafter wound around the hip pitch joint in the same direction as a rotation direction of the actuator, and then wound around the knee pitch joint in an opposite direction to the rotation direction of the actuator.

(9) The motion assist device according to (8) above, wherein the transmission part constituted of the wire is crossed between the hip pitch joint and the knee pitch joint.

(10) A motion assist device, including:

a thigh link worn on a thigh part of a leg of a user;

a knee pitch joint connected at a lower end of the thigh link in a freely rotatable manner;

a pelvis link worn on the thigh part of the leg;

a hip pitch joint integral with the pelvis link and connected to an upper end of the thigh link;

an actuator installed at a shank link adjacent to the thigh link; and

a transmission part transmitting a driving force of the actuator to the hip pitch joint and the knee pitch joint.

(11) The motion assist device according to (10) above, wherein

the transmission part transmits the driving force to the knee pitch joint in the same direction as a driving direction of the actuator, and transmits the driving force to the hip pitch joint in an opposite direction to the driving direction of the actuator.

(12) The motion assist device according to (10),

wherein the transmission part includes a wire which is wound around an output axis of the actuator, thereafter wound around the hip pitch joint in a same direction as a rotation direction of the actuator, and then wound around the knee pitch joint in an opposite direction to the rotation direction of the actuator.

(13) The motion assist device according to (12) above, wherein

the transmission part constituted of the wire is crossed between the knee pitch joint and the hip pitch joint.

(14) The motion assist device according to any one of (1), (6), and (10), further including:

a target torque determining part determining a torque target value of the actuator; and

an actuator control part which controls the actuator by torque control on the basis of the torque target value.

(15) The motion assist device according to (14), further including:

a joint angle measuring part which measures a joint angle of the joint unit; and

a torque measuring part which measures an external torque acting on the actuator,

wherein the actuator control part controls the actuator by torque control in a manner that a desired relationship is established between the joint angle measured by the joint angle measuring part and the external torque measured by the torque measuring part.

(16) The motion assist device according to (15),

wherein the actuator control part includes a disturbance observer which calculates a disturbance torque τ_d at a time when the actuator is driven with a target torque τ_A,

wherein a joint angular acceleration target value is obtained from an ideal response model of the actuator, in which the joint angular acceleration target value, which is achieved by the actuator responding on the basis of the target torque τ_A, an external torque τ_e, and a joint angle speed obtained by differentiating the joint angle by time, is calculated and output, and

wherein the actuator control part determines a command torque τ for the actuator in a current control period, by correcting a torque target value τ^{ref}, which is obtained by multiplying the joint angular acceleration target value by an inertia nominal value J_n in the actuator, with the disturbance torque τ_d, which is obtained by the disturbance observer in a previous control period.

(17) The motion assist device according to (6) or (10), further including:

a state detecting part which detects whether the leg is in a state of standing leg or an idling leg;

a joint angle measuring part which measures joint angles of the hip pitch joint and the knee pitch joint; and

a target torque determining part which determines the torque target value based on the joint angle of the hip pitch joint or the knee pitch joint depending on whether the leg is in the state of the standing leg or the idling leg,

wherein the actuator control part controls the actuator by torque control on the basis of the torque target value.

(18) The motion assist device according to (17),

wherein the target torque determining part determines the torque target value on the basis of the joint angle of the knee pitch joint when the leg is the standing leg, and determines the torque target value based on the joint angle of the hip pitch joint when the leg is the idling leg.

(19) The motion assist device according to (17),

wherein the state detecting part includes a contact switch which determines whether or not a foot part of the leg is grounded.

(20) A motion assist method for assisting motion of a user using the motion assist device according to any one of (1), (6), and (10) above, including:

determining a target torque for the actuator; and

controlling the actuator by torque control on the basis of the torque target value.

(21) A motion assist method for assisting motion of the user using the motion assist device according to (6) or (10), including:

detecting whether the leg is in a state of the standing leg or the idling leg;

measuring joint angles of the hip pitch joint and the knee pitch joint;

determining the torque target value based on the joint angle of the hip pitch joint or the knee pitch joint depending on whether the leg is in the state of the standing leg or the idling leg; and

controlling the actuator by torque control on the basis of the torque target value.

(22) The motion assist method according to (21) above, wherein

in determining the target torque, when the leg is the standing leg, the torque target value is determined on the basis of the joint angle of the knee pitch joint, and when the leg is the idling leg, the torque target value is determined on the basis of the joint angle of the hip pitch joint.

The technology of the present disclosure has been described in detail above with reference to the specific embodiments. However, it is obvious that those skilled in the art can make corrections or substitutions to the embodiments within the scope of the technology of the present disclosure.

In this specification, the description has been centered on the embodiment in which the technology of the present disclosure is applied to the leg assist suit. However, the scope of the technology of the present disclosure is not limited to this. The technology of the present disclosure can be applied to various types of assist suits worn on portions of a person other than the leg to assist various motions of the person other than walking.

In other words, the technology of the present disclosure has been described in a form of exemplification, and the description contained in this specification is not to be interpreted as limiting. Consideration should be given to the scope of the claims in order to determine the scope of the technology of the present disclosure.

The present disclosure contains subject matter related to that disclosed in Japanese Priority Patent Application JP 2012-221907 filed in the Japan Patent Office on Oct. 4, 2012, the entire content of which is hereby incorporated by reference.

What is claimed is:

1. A device comprising:

a first link;

a first joint connected at one end of the first link in a freely rotatable manner;

a second link;

a second joint integral with one end of the second link and coupled to the other end of the first link;

a single actuator installed at one of the first link, the second link, and a third link adjacent to the first link, wherein the single actuator is installed at a separate location from both of the first joint and the second joint; and a transmission part configured to transmit a driving force of the single actuator to both of the first joint and the second joint through a wire that is wound around an output axis of the single actuator and crossed between the first joint and the second joint, such that the wire is wound around the first joint in a same direction as a winding direction of the wire around the output axis of the single actuator, and then the wire is wound around the second joint in an opposite direction to the winding direction of the wire around the output axis of the single actuator.

2. The device according to claim **1**,

wherein the transmission part is further configured to transmit the driving force of the single actuator in a manner that a proportional relationship is established between a torque generated at the first joint and a torque generated at the second joint.

3. The device according to claim **1**,

wherein the transmission part is further configured to transmit the driving force of the single actuator in a manner that driving directions of the first joint and the second joint are opposite to each other.

4. The device according to claim **1**,

wherein the first link is a thigh link configured to be worn on a thigh part of a leg of the user,

wherein the first joint is a hip pitch joint connected at an upper end of the thigh link in a freely rotatable manner,

wherein the second link is a shank link configured to be worn on a shank part of the leg,

wherein the second joint is a knee pitch joint integral with an upper end of the shank link and coupled to a lower end of the thigh link, and

wherein the single actuator is installed at the thigh link.

5. The device according to claim **4**, further comprising:

a state detecting part configured to detect whether the leg is in a state of standing leg or an idling leg;

a joint angle measuring part configured to measure joint angles of the hip pitch joint and the knee pitch joint; and

a target torque determining part configured to determine a torque target value based on the joint angle of the hip pitch joint or the knee pitch joint depending on whether the leg is in the state of the standing leg or the idling leg,

wherein an actuator control part is configured to control the single actuator by torque control on the basis of the torque target value.

6. The device according to claim **5**,

wherein the target torque determining part is further configured to determine the torque target value on the basis of the joint angle of the knee pitch joint when the leg is the standing leg, and determine the torque target value based on the joint angle of the hip pitch joint when the leg is the idling leg.

7. The device according to claim **5**,

wherein the state detecting part includes a contact switch configured to determine whether or not a foot part of the leg is grounded.

8. The device according to claim **1**,

wherein the first link is a thigh link configured to be worn on a thigh part of a leg of the user,

wherein the second joint is a knee pitch joint connected at a lower end of the thigh link in a freely rotatable manner,

wherein the third link is a pelvis link configured to be worn adjacent to the thigh part of the leg,

wherein the first joint is a hip pitch joint integral with the pelvis link and coupled to an upper end of the thigh link, and

wherein the single actuator is installed at the second link, which is a shank link adjacent to the thigh link.

9. The device according to claim **1**, further comprising:

a target torque determining part determining a torque target value of the single actuator; and

an actuator control part configured to control the single actuator by torque control on the basis of the torque target value.

10. The device according to claim **9**, further comprising:

a joint angle measuring part configured to measure a joint angle of each joint of the first joint and the second joint; and

a torque measuring part configured to measure an external torque acting on the single actuator,

wherein the actuator control part is further configured to control the single actuator by torque control in a manner that a desired relationship is established between the joint angle of each joint measured by the joint angle measuring part and the external torque measured by the torque measuring part.

11. The device according to claim **10**,

wherein the actuator control part includes a disturbance observer which calculates a disturbance torque τ_d at a time when the single actuator is driven with a target torque τ_A,

wherein the actuator control part is further configured to control the single actuator by the torque control based on a joint angular acceleration target value obtained from an ideal response model of the single actuator, in which the joint angular acceleration target value, which is achieved by the single actuator responding on the basis of the target torque τ_A, an external torque τ_e, and a joint angle speed obtained by differentiating the joint angle by time, is calculated and output,

wherein the actuator control part is further configured to determine a command torque τ for the single actuator in a current control period by correcting a torque target value τ^{ref},

wherein the torque target value τ^{ref} is obtained by multiplying the joint angular acceleration target value by an inertia nominal value J_n in the single actuator, and

wherein the torque target value τ^{ref} is corrected with the disturbance torque τ_d, which is obtained by the disturbance observer in a previous control period.

12. A method for assisting motion of the user using the device according to claim **4**, the method comprising:

detecting whether the leg is in a state of the standing leg or the idling leg;

measuring joint angles of the hip pitch joint and the knee pitch joint;

determining a torque target value based on the joint angle of at least one of the hip pitch joint and the knee pitch joint depending on whether the leg is in the state of the standing leg or the idling leg; and

controlling the single actuator by torque control on the basis of the torque target value.

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